

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
17 January 2002 (17.01.2002)

PCT

(10) International Publication Number  
**WO 02/04357 A1**

(51) International Patent Classification<sup>7</sup>: **C02F 1/469,**  
B01D 61/48, B01J 47/08

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(21) International Application Number: **PCT/GB01/02967**

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(22) International Filing Date: **5 July 2001 (05.07.2001)**

(25) Filing Language:

English

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,  
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,  
CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM,  
HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK,  
LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX,  
MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL,  
TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(26) Publication Language:

English

(30) Priority Data:  
**0016846.8** 10 July 2000 (10.07.2000) GB

(84) Designated States (*regional*): ARIPO patent (GH, GM,  
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian  
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European  
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,  
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,  
CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

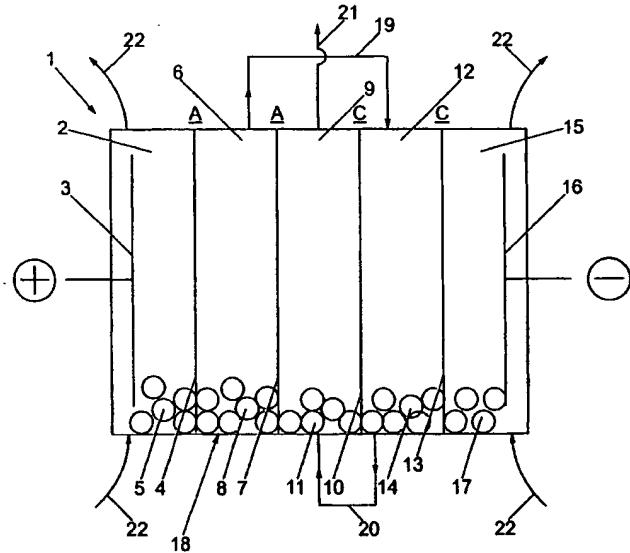
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Published:

— with international search report

[Continued on next page]

(54) Title: ELECTRODEIONISATION APPARATUS



**WO 02/04357 A1**

(57) Abstract: An electrodeionisation apparatus comprising, successively: means defining an anode chamber, means defining one or more anion exchange chambers, means defining one or more mixed exchange chambers, means defining one or more cation exchange chambers, and means defining a cathode chamber, the anion, mixed and cation exchange chambers providing a flow path for water to be purified, is described. The present invention incorporates advantages of both separate resin bed and mixed resin bed technology.



— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

1       Electrodeionisation Apparatus

2

3       The present invention relates to an  
4       electrodeionisation apparatus for purifying water  
5       and method therefor.

6

7       Apparatus and methods for electrodeionisation to  
8       provide purified water are well known, see for  
9       example our GB-A-2311999 and US 4687561. Generally,  
10      water to be purified is passed along a deionising  
11      path set between an anode and a cathode. The  
12      application of a potential difference between the  
13      anode and cathode causes anions and cations in the  
14      impure water to migrate towards their respective  
15      attracting electrodes through perm-selective  
16      membranes.

17

18      In general, such apparatus has the chambers for  
19      exchanging anions and cations juxtaposed so  
20      that the anions and cations removed from the water  
21      being purified both travel towards one or more  
22      'concentrating' chambers, through which a desalting

1 stream flows to remove the unwanted anions and  
2 cations.

3

4 It is an object of the present invention to provide  
5 a simplified electrodeionisation apparatus and  
6 method.

7

8 According to one aspect of the present invention,  
9 there is provided an electrodeionisation apparatus  
10 comprising, successively:

11

12 means defining an anode chamber,  
13 means defining one or more anion exchange chambers,  
14 means defining one or more mixed exchange chambers,  
15 means defining one or more cation exchange chambers,  
16 and  
17 means defining a cathode chamber,

18

19 the anion, mixed and cation exchange chambers  
20 providing a flow path for water to be purified.

21

22 By locating the or each anion exchange chamber next  
23 to the anode chamber, and locating the or each  
24 cation exchange chamber next to the cathode chamber,  
25 the apparatus of the present invention provides an  
26 opposite or reverse flow-path for exchanged anions  
27 and cations than prior apparatus. The exchanged  
28 anions and cations in the water being purified are  
29 directly attracted to neighbouring electrodes,  
30 rather than being attracted to distal electrodes  
31 located across opposing exchange chambers of prior  
32 electrodeionisation apparatus.

1     In one embodiment of the present invention, the  
2     apparatus involves one anion exchange chamber and  
3     one cation exchange chamber.

4

5     Located between the chambers are perm-selective  
6     membranes as are known in the art. Those membranes  
7     located between the or each central mixed exchange  
8     chamber and the cathode chamber should be cation  
9     membranes, and those membranes located between the  
10    or each mixed exchange chamber and the anode chamber  
11    should be anion membranes.

12

13    Preferably, the or each anion exchange chamber  
14    partly, substantially or wholly contains anion  
15    exchange material, and the or each cation exchange  
16    chamber partly, substantially or wholly contains  
17    cation exchange material.

18

19    Preferably, the anode chamber partly, substantially  
20    or wholly contains ion exchange material, preferably  
21    cation exchange material. Preferably, the cathode  
22    chamber, partly, substantially or wholly contains  
23    ion exchange material, more preferably cation  
24    exchange material. Also preferably, the or each  
25    mixed exchange chamber partly, substantially or  
26    wholly contains mixed ion exchange material. Ion  
27    exchange materials are known in the art, one example  
28    being resin beads.

29

30    The anode and cathode chambers are preferably  
31    flushed with a desalting stream such as water to  
32    elute ions from the system as concentrate.

1       In another embodiment of the present invention,  
2       water to be purified is firstly passed through an  
3       anion exchange chamber of the apparatus, then  
4       through a cation exchange chamber, and subsequently  
5       through a mixed exchange chamber.

6

7       Alternatively, water to be purified is passed  
8       through a cation exchange chamber, then through an  
9       anion exchange chamber, and subsequently through a  
10      mixed exchange chamber.

11

12      Where apparatus of the present invention involves  
13      two or more anion exchange chambers and/or two or  
14      more cation exchange chambers and/or two or more  
15      mixed exchange chambers, then impure water flow path  
16      could be directed through subsequent anion exchange  
17      chambers and/or subsequent cation exchange chambers  
18      and/or subsequent mixed exchange chambers in the  
19      same or any suitable or relevant order.

20

21      In a third embodiment of the present invention,  
22      water to be purified by the present apparatus is  
23      combined with already purified water, so reducing,  
24      by dilution, the load on the exchange materials.  
25      The already purified water may be provided from a  
26      separate source, or be provided by re-circulating  
27      outflow from the present apparatus, which outflow  
28      could be temporarily held in a reservoir such as a  
29      holding tank.

30

31      According to a fourth embodiment of the present  
32      invention, the anion, cation and mixed exchange

1        chambers are relatively thick compared with chambers  
2        of prior art electrodeionisation apparatus. The  
3        simplicity of the present invention allows thicker  
4        chambers and beds of ion exchange materials to be  
5        used, compared with the conventional view that  
6        thinner beds are necessary to maintain electric  
7        current flow thereacross.

8

9        The present invention also extends to a 'multiple'  
10      unit still only involving one set of electrodes.  
11      For example, the unit could be arranged: anode  
12      (chamber), anion, mixed, cation, concentrate...,  
13      anion, mixed, cation, concentrate..., anion, mixed,  
14      cation, cathode.

15

16      According to a second aspect of the present  
17      invention, there is provided a method of  
18      electrodeionisation comprising causing or allowing  
19      water to be purified to flow through an anion  
20      exchange chamber neighbouring an anode chamber,  
21      followed by flow through a cation exchange chamber  
22      neighbouring a cathode chamber, or vice versa,  
23      followed by flow through a mixed exchange chamber  
24      located between the anion exchange chamber and the  
25      cation exchange chamber.

26

27      The method of the present invention could use  
28      electrodeionisation apparatus as described above.  
29      In the method of the present invention, the water to  
30      be purified could be pre-mixed with a proportion of  
31      already purified water.

32

1 In general, water may be passed through each chamber  
2 independently, allowing different flow rates,  
3 including no flow, at different times.

4

5 An embodiment of the present invention will now be  
6 described by way of example only, and with reference  
7 to the accompanying drawing, Figure 1, which is a  
8 schematic cross-sectional side view of apparatus  
9 according to the present invention.

10

11 Referring to the drawing, Figure 1 shows an  
12 electrodeionisation apparatus in the form of a stack  
13 (1). The stack (1) has five chambers. The first  
14 chamber (2) is an anode chamber bounded on one side  
15 by an anode (3) and on the other by an anion  
16 membrane (4). The anode chamber (2) contains cation  
17 exchange resin beads (5). Juxtaposed the anode  
18 chamber (2) is an anion exchange chamber (6) bounded  
19 on one side by the anion membrane (4), and on the  
20 other side by a second anion membrane (7). The  
21 anion exchange chamber (6) contains anion exchange  
22 resin beads (8). Next to the anion exchange chamber  
23 (6) is a mixed exchange chamber (9), bounded by the  
24 second anion membrane (7) and a cation membrane  
25 (10). This chamber (9) contains mixed ion exchange  
26 resin beads (11).

27

28 Juxtaposed the mixed exchange chamber (9), there is  
29 a cation exchange chamber (12) bounded by the cation  
30 membrane (10), and a second cation membrane (13).  
31 The cation exchange chamber (12) contains cation  
32 exchange resin beads (14).

1 Juxtaposed the cation exchange chamber (12) lies a  
2 cathode chamber (15) bounded by the second cation  
3 exchange membrane (13) and a cathode (16). The  
4 cathode chamber (15) contains cation exchange resin  
5 (17).

6

7 The nature and form of the electrodes, membranes and  
8 ion exchange materials are all known in the art.

9

10 In use, impure feed water (18) enters the stack (1),  
11 and firstly enters the anion exchange chamber (6).  
12 The anion exchange resin beads (8) in this chamber  
13 (6) replace the anions in the feed water with  
14 hydroxide ions from the resin beads (8). The anions  
15 then move towards and through the anion exchange  
16 membrane (4) to the anode chamber (2). The driving  
17 force for this movement is an electrical potential  
18 placed between the anode (3) and cathode (16). The  
19 feed water (19) exiting this chamber (6) is then  
20 passed into the cation exchange chamber (12), where  
21 the cation exchange resin beads (14) exchange  
22 cations in the feed water for hydrogen ion. The  
23 cations then move towards and through the cation  
24 exchange membrane (13) to the cathode chamber (15).

25

26 The water (20) exiting this chamber (12) is then  
27 passed into the mixed resin chamber (9). The mixed  
28 resin beads remove both anionic and cationic ions  
29 that have passed through the first two chambers (6,  
30 12). Ions removed in the mixed exchange chamber (9)  
31 pass through the relevant ion exchange membranes (7,  
32 10) to the single exchange chambers, where they, as

1 well as ions exchanged therein, pass through the  
2 relevant ion exchange membranes into the electrode  
3 compartments.

4

5 From the mixed chamber (9) final product water (21)  
6 is obtained for use.

7

8 The electrode compartments (2, 15) are flushed with  
9 water to elute the ions from the system as  
10 concentrate (22). This flow may be in series or in  
11 parallel.

12

13 In an alternative arrangement, feed water could  
14 firstly be passed into the cation exchange chamber  
15 (12), followed by the anion exchange chamber (6),  
16 before being passed into the mixed exchange chamber  
17 (9). This alternative flow-path arrangement also  
18 allows the removal of precipitative cations such as  
19 calcium before they reach the anion exchange  
20 material (8) and anion membranes (4, 7) on which  
21 they are likely to precipitate. As these ions pass  
22 into the cathode exchange chamber (12), it is  
23 preferable to maintain a low pH in the cathode  
24 exchange chamber (12) and to feed the cathode  
25 chamber (15) with water, or acid, devoid of  
26 precipitative ions.

27

28 The product water (21) exiting the mixed exchange  
29 chamber (9) of the present invention has been found  
30 to be of low ionic content. Indeed, the flow rate  
31 and purification achieved by the present invention  
32 is comparable with prior art EDI apparatus, which

1 generally involves a significantly more complex  
2 arrangement of chambers.

3

4 In another arrangement of the present invention, the  
5 feed water (18) is pre-mixed with a proportion of  
6 already purified water (21). By diluting the load  
7 (i.e. concentration of impure ions to be removed  
8 from the water), a higher flow rate through the  
9 apparatus can be achieved.

10

11 Indeed, a ratio of 10:1 of already purified  
12 water:impure water allows a flow rate of at least  
13 2/3 litres per minute through the apparatus shown in  
14 Figure 1. The already purified water could be  
15 supplied from a separate source, or be re-circulated  
16 product water (21) from the present apparatus.

17

18 The following test data using a design of stack as  
19 shown in Figure 1 confirms the benefit of the  
20 present invention:

21

22 Example 1

23

24 A stack with internal plate dimensions 150 mm x 66  
25 mm x 15 mm was operated on a blend of reverse  
26 osmosis permeate and deionised water. With a feed  
27 of conductivity 18.2 µS/cm (adjusted to 25°C) the  
28 stack purified 0.55 litres per minute to a  
29 conductivity of 0.073 µS/cm when a current of 1.3  
30 amps was applied between the electrodes. With a  
31 feed of 7.2 µS/cm, 1.37 litres per minute were  
32 purified to 0.092 µS/cm at 1.3 amps.

## 1      Example 2

2

3      A stack with dimensions 135 mm x 68 mm x 10 mm was  
4      operated recirculating from a tank. Water was  
5      intermittently taken off after the stack and extra  
6      make up was fed to the stack from a reverse osmosis  
7      membrane. The applied current was 3.16 amps. When  
8      the reverse osmosis unit was operating the feed to  
9      the stack was 12.5  $\mu\text{S}/\text{cm}$  and this was purified at a  
10     rate of 1.95 litres per minute to 0.062  $\mu\text{S}/\text{cm}$ . When  
11     recirculating from the tank the feedwater reduced in  
12     conductivity to 0.32  $\mu\text{S}/\text{cm}$  at which time the product  
13     water was 0.057  $\mu\text{S}/\text{cm}$ .

14

15     The present invention incorporates advantages of  
16     both separate resin bed and mixed resin bed  
17     technology. Separate resin beds are beneficial for  
18     removing known amounts of defined ionic impurity  
19     types, both anion and cation, and the current  
20     passing through that resin bed can be utilised in  
21     removing solely that type of ion.

22

23     If the feed water is first passed through a cation  
24     exchange resin bed, cations can be removed from the  
25     solution causing a reduction in the solution pH.  
26     Similarly, an anion resin bed will increase the pH.  
27     Changes in pH help to prevent bacterial growth, and  
28     may also be used to prevent precipitation, or  
29     increase the ionic nature of weakly charged species.

30

1     Meanwhile, mixed resin beds have been noted to  
2     handle high flow rates of water whilst still  
3     achieving high levels of purification.

4

5     The present invention has several further  
6     advantages. It provides a compact purification unit  
7     using a single set of electrodes. It is of simple  
8     form, allowing simplified manufacturing thereof,  
9     with less complication and therefore with reduced  
10    risk of potential breakdown.

11

12    As mentioned before, water may be passed through  
13    each chamber independently, allowing different flow  
14    rates, including no flow, at different times.

15

16    Also, the number of chambers of the present  
17    invention, possibly being only five, are less than  
18    many prior art apparatus, thus reducing the problems  
19    of back pressure on the feed water, and allowing a  
20    faster flow rate therethrough. The use of  
21    relatively thick chambers in the present invention  
22    also reduces the feed water back pressure.

23

24    Furthermore, feed water through the present  
25    invention does not pass through the anode or cathode  
26    chambers as occurs in some prior art apparatus,  
27    thereby avoiding the problem of gas in the product  
28    water.

29

30    Also, the present invention aids removal of weakly  
31    ionised species, and can be used in a manner to  
32    inhibit precipitative fouling.

1      Claims

2

3      1. An electrodeionisation apparatus comprising,  
4            successively:

5

6            means defining an anode chamber,  
7            means defining one or more anion exchange  
8            chambers,  
9            means defining one or more mixed exchange  
10          chambers,  
11          means defining one or more cation exchange  
12          chambers, and  
13          means defining a cathode chamber,  
14  
15          the anion, mixed and cation exchange chambers  
16          providing a flow path for water to be purified.

17

18      2. Apparatus as claimed in Claim 1 involving one  
19          anion exchange chamber and one cation exchange  
20          chamber.

21

22      3. Apparatus as claimed in Claim 1 or Claim 2  
23          wherein two or more of the chambers are divided  
24          by perm-selective membranes.

25

26      4. Apparatus as claimed in Claim 3 wherein any  
27          membrane located between the or each central  
28          mixed exchange chamber and the cathode chamber  
29          is a cation membrane.

30

31      5. Apparatus as claimed in Claim 3 or Claim 4  
32          wherein any membrane located between the or

- 1       each mixed exchange chamber and the anode  
2       chamber is an anion membrane.
- 3
- 4       6. Apparatus as claimed in any one of the  
5       preceding Claims wherein the or each anion  
6       exchange chamber partly, substantially or  
7       wholly contains anion exchange material.
- 8
- 9       7. Apparatus as claimed in any one of the  
10      preceding Claims wherein the or each cation  
11      exchange chamber partly, substantially or  
12      wholly contains cation exchange material.
- 13
- 14      8. Apparatus as claimed in any one of the  
15      preceding Claims wherein the anode chamber  
16      partly, substantially or wholly contains ion  
17      exchange material.
- 18
- 19      9. Apparatus as claimed in any one of the  
20      preceding Claims wherein the cathode chamber,  
21      partly, substantially or wholly contains ion  
22      exchange material.
- 23
- 24      10. Apparatus as claimed in Claim 8 or Claim 9  
25      wherein the ion exchange material is cation  
26      exchange material.
- 27
- 28      11. Apparatus as claimed in any one of the  
29      preceding Claims wherein the or each mixed  
30      exchange chamber partly, substantially or  
31      wholly contains mixed ion exchange material.
- 32

- 1       12. Apparatus as claimed in any one of Claims 6 to  
2            11 wherein the ion exchange material is resin  
3            beads.
- 4
- 5       13. Apparatus as claimed in any one of the  
6            preceding Claims wherein the or each anion,  
7            cation and/or mixed exchange chambers are  
8            between 5-20mm wide.
- 9
- 10      14. A method of electrodeionisation comprising  
11            causing or allowing water to be purified to  
12            flow through an anion exchange chamber  
13            neighbouring an anode chamber, followed by flow  
14            through a cation exchange chamber neighbouring  
15            a cathode chamber, followed by flow through a  
16            mixed exchange chamber located between the  
17            anion exchange chamber and the cation exchange  
18            chamber.
- 19
- 20      15. A method of electrodeionisation comprising  
21            causing or allowing water to be purified to  
22            flow through a cation exchange chamber  
23            neighbouring a cathode chamber, followed by  
24            flow through an anion exchange chamber  
25            neighbouring an anode chamber, followed by flow  
26            through a mixed exchange chamber located  
27            between the anion exchange chamber and the  
28            cation exchange chamber.
- 29
- 30      16. A method as claimed in Claim 14 or claim 15  
31            wherein the flow of water through each chamber  
32            is independent of other flows.

- 1       17. A method as claimed in any one of Claims 14 to  
2           Claim 16 wherein the anode and cathode chambers  
3           are flushed with a desalting stream.
- 4
- 5       18. A method as claimed in any one of Claims 14 to  
6           17 which involves two or more anion exchange  
7           chambers and/or two or more cation exchange  
8           chambers and/or two or more mixed exchange  
9           chambers, wherein the water to be purified  
10          flows through one or more subsequent anion  
11          exchange chambers and/or one or more subsequent  
12          cation exchange chambers and/or one or more  
13          subsequent mixed exchange chambers in the same  
14          or any suitable or relevant order.
- 15
- 16       19. A method as claimed in any one of Claims 14 to  
17           18 wherein the water to be purified is combined  
18           with purified water prior to  
19           electrodeionisation.
- 20
- 21       20. A method as claimed in Claim 19 wherein the  
22           water to be purified is combined with water  
23           provided by outflow product of the method of  
24           Claims 14 to 18.
- 25
- 26       21. A method as claimed in any one of Claims 14 to  
27           20 wherein apparatus as claimed in any one of  
28           Claims 1 to 13 is used.

1 / 1

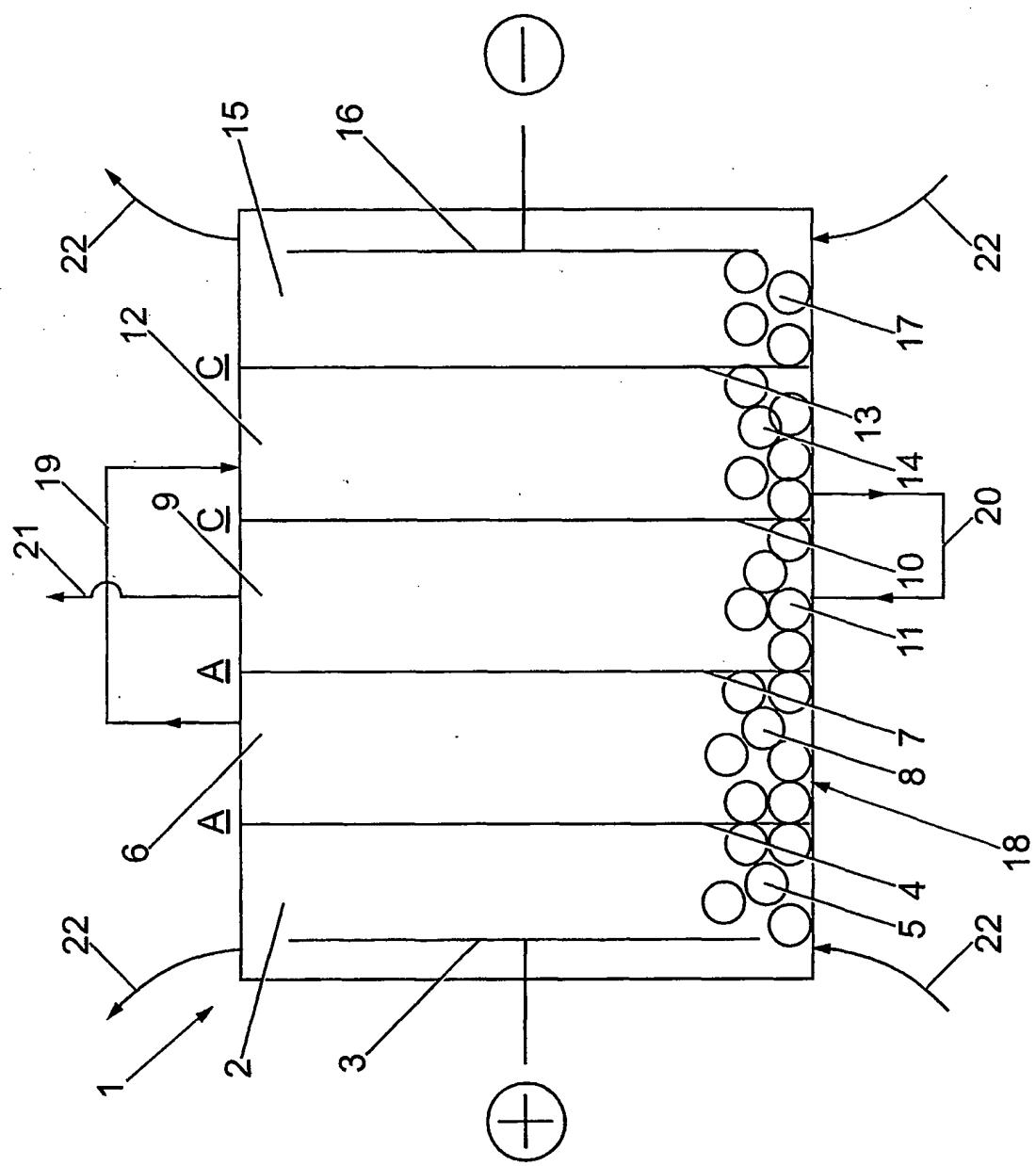


Fig. 1

## INTERNATIONAL SEARCH REPORT

Inte  
nal Application No  
PCT/EP 01/02967

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 C02F1/469 B01D61/48 B01J47/08

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 C02F B01D B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 32 38 280 A (LIEBER HANS WILHELM PROF DR IN) 19 April 1984 (1984-04-19) claims 1-3,5; figures 1,2,5	1-21
A	GB 2 311 999 A (ELGA GROUP SERVICES LTD) 15 October 1997 (1997-10-15) cited in the application claims 1,5; figure 1	1-21
A	US 4 687 561 A (KUNZ GERHARD) 18 August 1987 (1987-08-18) cited in the application claim 1.16; figure 1	1-21
A	US 3 869 376 A (TEJEDA ALVARO R) 4 March 1975 (1975-03-04) figure 5	1-21

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of mailing of the international search report

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